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Steam Power in China

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The power that drove the machines of the Industrial Revolution was produced by the steam engine's valved piston-cylinder mechanism, which turned the pressure differential within and without the cylinder into a motive force. Its success relied on machine tools that produced metal parts with precision and thermodynamics that facilitated the accurate calculation of heat and motive force. Although premodern Chinese blacksmiths' wooden double-acting piston bellows shared a similar mechanism, human arms were the source of their power (Needham, 1962, pp. 136–137). Previously, China had not had a strong tradition in using metal cutting machine tools. Nor was the Chinese understanding of the atmosphere and heat expressed in mathematical formulae. Therefore, the transfer of steam engine technology faced great technical and scientific challenges. The process of adaptation began with Chinese encountering paddlewheel steamships.

From the late1820s to the mid-1830s, several foreign steamships visited the port of Guangzhou, south China. The sight of smoke puffing out of the novel vessels' funnels and their rotating paddlewheels attracted attention. In 1828, an anonymous Chinese observer described that a flame fed by burning coal in a copper cylinder drove the paddlewheels. During the Opium War (1839–1842), in which British firearms and steam gunboats defeated Qing troops and war junks, the government officials who witnessed the British steamers gave similar accounts. Their misunderstandings led to a few failed attempts to build paddlewheel boats to fight against the British fleet. Having discovered that smoke had no effect, the Chinese inventors adopted a traditional technology, the treadmill mechanism, to build water wheel boats (*shuilunchuan* 水輪船), a type of treadmill paddlewheel boat that could be traced to the twelfth century. Probably for that reason, the Chinese named the steamer as "fire wheel boat" (*huolunchuan* 火輪船). As late as 1842, a Qing senior official who boarded a British steam warship reported to the emperor that the paddlewheels were driven by fire according to the principle of the clock (Wang, 2010).

Unable to understand the steam mechanism, Qing government officials sought foreign expertise. In early 1842, a Guangdong merchant commissioned foreign technicians in Macau, a Portuguese colony, to build a steamer and donated it to the government. Although the emperor forbade the pursuit of the technology because of its high cost and dubious effectiveness, in 1845, a senior official in Guangdong recruited an American shipwright to build a steamer. Unfortunately, the building work halted after the shipwright died. Qing government officials did not experiment further with steamship technology until the early 1860s.

However, not all Chinese people misunderstood the steam mechanism. Ding Gongcheng, a merchant interested in gunnery, figured out the steam mechanism when he was living in Guangzhou. His book, *Yanpaotushuo* (Illustrative Treatise on Gunnery), printed in 1841, contained an essay describing his experiments with the steam engine. According to the essay, Ding hired an artisan to build a model locomotive, which was nearly 1.9 ft long and 7.6 in. wide. He used the same engine to build a model steamboat, which was4.4 ft long and 1.6 ft wide. Both models ran well. Ding admitted that a full-scale steamer could not be built due to the lack of proper tools. His friend Zheng

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Fuguang tried to figure out the steam mechanism by studying diagrams and a model steamer but did not conduct any experiments. In his essay on the paddlewheel steamer, which was included in his 1846 book on optics, he correctly described the mechanism. Although Ding and Zheng's writings circulated among the Chinese literati, there is no evidence that anyone else learned about the steam mechanism from those essays.

After the war, the Chinese people had more opportunities to observe the steam engine, because, with the opening of five ports to foreign trade, more foreign steamers were visiting China. Additionally, foreign-owned machine shops and dockyards were set up in the treaty ports to service those vessels. In Shanghai, the number of dockyards rose from one in the late 1840s to nine in the 1860s. By 1860, three docks were operating in Hong Kong and four near Guangzhou. Those dockyards hired foreign technicians and Chinese workmen (Xin, 1999, pp. 34–36, 40–42).

Furthermore, because of the Protestant missionary publications in the treaty ports, which aimed at converting Chinese people to Christianity by introducing general knowledge of Western science and technology, Chinese literati had greater opportunity to learn about the steam engine. For example, *Xia'erguanzhen* (Chinese Serial), which began publication in Hong Kong in 1853, and *Bowuxinbian* (Natural Philosophy), which was first published in Guangzhou but after 1855 in Shanghai, contained short essays about the steam engine. Some of the dockyards became leading private shipbuilding enterprises of the Far East in the late nineteenth century. Those changes were the background of the first Chinese-built steamer in the early 1860s.

Two more wars aggravated Qing China's need for steam technology. In the Taiping Rebellion (1851–1865), which was one of the most devastating civil wars in Chinese history, Western firearms and steam gunboats proved the key factor that decided the results of battles. In the Second Opium War (1856–1860), the Anglo-French allied forces overwhelmed Chinese defenses and seized the capital Beijing, forcing the Qing court to flee. Only in such a critical situation did senior officials call for self-strengthening with foreign firearms and steamships (Kuo & Liu, 1978). In 1861, Zeng Guofan, a leading anti-Taiping commander, recruited Hua Hengfang and Xu Shou, two literati interested in mathematics and chemistry, into his staff and instructed them to experiment on building steamships. They learned the basics of the steam mechanism from the sketchy description published in the *Bowuxinbian* and observed the steam engines on board foreign steamers. After building a model steam engine and a test steamboat, they completed in 1863 the *Huanghu*, which was fitted with a high-pressure engine and a tubular boiler, without foreign assistance (Wang, 2010).

After the Taiping rebels were defeated, the Qing government established modern arsenals that employed steam-driven machine tools. Among these arsenals, the Jiangnan Arsenal (*Jiangnanzhizaoju*, 江南製造局) was one of the foremost firearm manufacturers and shipyards in nineteenth-century China. The arsenal was established in 1865 by Li Hongzhang, Zeng Guofan's lieutenant in the anti-Taiping campaign, on the basis of a foreign-owned machine shop. Zeng, who took over the Arsenal from Li, added the metalworking factory, the boiler shop, the foundry, the dock, as well as the fitting and setting-up shop to its facilities in order to build steamers. The Arsenal recruited foreign technicians to direct Chinese workmen, who, in 1869, numbered 1,000. In 1868, it built its first paddlewheel steamboat, which was fitted with a refurbished 150-hp steam engine. The Arsenal also built five screw-propelled steam gunboats and their engines by 1876. After that, it focused on firearm manufacture but also completed one steel-hull gunboat in 1885 before it suspended its shipbuilding program (Xin, 1999, pp. 107–118).

Although the Jiangnan Arsenal had made some technical progress, a more complete program for the wholesale transfer of steamship-building technology from its theoretical foundation to its application was established in the Fuzhou Navy Yard (*Fuzhou chuanzheng*, 福州船政局). The Navy Yard was established in 1866 by Zuo Zongtang, another senior official who rose to

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prominence in the Taiping Rebellion. It had four major workshops: the metalworking shop, the boiler shop, the fitting shop, and the foundry. These shops could produce every part of a steamer, from the engine to the barometer, from raw materials. It recruited a team of 75 French managers and technicians, including the French naval officer Prosper Giquel, to direct Chinese workers in the ship and engine building works. By 1868, the Navy Yard employed as many as 3,000 Chinese workers who were given on-the-job training in drafting, carpentry, machine tool operating, and metalworking. It completed its first screw-propelled steamboat (223 × 29.5 × 13.2 ft dimension, 1,450 t displacement, 150 hp single-cylinder engine) in 1869 and, by the end of 1870, built four more similar vessels. It completed its first domestically built engine in 1871 (Pong, 1994, pp. 203–244).

In order to train naval officers and marine engineers, the Navy Yard established the Fuzhou Naval School (*Chuanzhengxuetang* 船政學堂), which had two divisions: the school of navigation and the school of naval construction. The latter recruited French teachers to teach French, arithmetic, and geometry to students as a prerequisite for physics, descriptive geometry, trigonometry, analytical geometry, calculus, and mechanics. The students were also required to gain practical experience by participating in the shipbuilding works. The number of the students was not large. By 1874, 39 students attended the school. Although the students managed to design and direct the building of a small steamboat without the French technicians' assistance in 1876, the naval yard considered the technological environment of China could not make them competent engineers. Hence, in 1877, it sent some of the students to Europe for further training.

After the expiry of the contract with the French technicians in 1874, the Navy Yard continued to upgrade its technology. Between 1877 and 1880, it completed five ships fitted with the 750 hp compound engine, which was much more sophisticated than the single-cylinder reciprocating engine it had built before. Then, it further introduced the triple expansion engine and, between1883 and 1886, completed three cruisers that were fitted with purchased 2,400 hp engines of such a kind. It also introduced steel-hull construction and, between 1888 and 1907, built 13 steel-hulled warships. Then, it ceased to build any ships because government funding stopped. In total, the Navy Yard completed 40 steam warships and merchant ships (Wang Zhiyi 1986, p. 99, 110).

The demise of the Fuzhou Navy Yard did not mark the end of China's steamship-building ambitions. The Jiangnan Arsenal's shipbuilding arm became the independent Jiangnan Dockyard in 1905, which recruited a team of foreign technicians to take over the managerial and technical works. It became a successful government-owned enterprise through competing in the shipbuilding business by accepting orders from the Chinese or foreign governments as well as shipping companies. It built sea-going cargo ships and also small displacement gunboats and cargo barges.

Beyond arsenals and shipyards, steam power was mainly used in the shipping business, which was booming after the 1860s, when the conflicts with Britain and France were resolved and the civil war ended. In 1872, when the first Chinese steam navigation company was formed, there had been as many as 13 foreign shipping companies, mostly American and British, operating in Chinese waters (Zhu, 2008, p.4). The number of companies and mercantile steamers fluctuated, but in 1893, the three largest operators, the China Merchants' Steam Navigation Company, the China Steam Navigation Company, and the Indo-China Steam Navigation, had 26, 29, and 22 steamships respectively (Liu Kwang-ching. 1959, p.448).

In comparison, however, the railway industry grew slowly. From the 1860s, the Qing government had rejected foreign diplomats' lobbying for allowing foreigners to build railways (Kent, 1907, pp. 1–8). In 1876, a group of foreign merchants built a 9½ mile long light railway in Shanghai without obtaining official permission. After negotiation, the Qing government purchased the line and moved the equipment to Taiwan. Unfortunately the line was never rebuilt due to lack of funds (Pong, 1973). In the 1880s, railway building was still a controversial issue in politics. Yet, after the

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Sino-French War (1884–1885), the Qing government acknowledged the strategic importance of the technology and hence gave the power of managing railway building to the newly established Admiralty (*Haijunyamen* 海軍衙門). However, due to financial difficulties, the speed of construction remained slow. By 1895, only 650 miles of railway lines were completed, but the speed of development increased thanks to foreign loans. By the time the dynasty collapsed in 1910, 5,606 miles more lines had been constructed (Chen, 1981, pp. 6–9).

Because of the need for fuel and raw materials, the Qing government sponsored the opening of coalmines and iron mines with steam power. The Kaiping Coalmine in Zhili province and the Hanyang Iron Works in Hubei province were established in 1871 and 1890, respectively (Carlson, 1971; Quan, 1972). Those enterprises were profitable and survived well into the first half of the twentieth century. The Qing government officials were also willing to sponsor steam power in textile manufacturing. It established two cotton weaving and spinning mills, Shanghai Cotton Cloth Mill (1876) and Hubei Cotton Cloth Mill (1889), and one mechanized woolen mill in Lanzhou, Gansu province (1880). In total, by 1910, the Qing government set up 69 arsenals and factories that employed steam power.

In the private sector, before1895, Chinese or foreign entrepreneurs were slow to exploit steam power for legal reasons. The Treaty of Tientsin [Tianjin] between China and foreign powers only stipulated that foreigners were allowed to build residential houses, churches, hospitals, and graveyards. Accordingly, the Qing government forbade foreigners from establishing factories in China. Yet, it only prosecuted the key industries mentioned above but ignored those small factories such as a mechanized soybean oil mill in Niuzhuang (1868–1970) or flourmills in the treaty ports (Wang, 2013). The best available data suggest that by 1895, 88 mechanized factories had been established in the treaty ports (Feuerwerker, 1980, p. 29). The legal constraint was lifted by the Treaty of Shimonoseki (1895), which concluded the Sino-Japanese War (1894–1895), and allowed foreigners to establish factories. Thereafter, 136 more steam-powered factories were founded between 1895 and 1913 (Feuerwerker, 1980, p. 29).

The introduction of the theoretical knowledge of the steam engine to the wider Chinese public was achieved in a limited scope and depth by translation. In 1860, the Qing government established the School of Combined Learning (*Tongwen guan* 同文館) in Beijing for training translators. Apart from teaching foreign languages, it offered courses in Western science and technology. The textbook, Natural Philosophy (*Gewu rumen* 格物入門), gave an introduction to the atmosphere and its pressure. It also explained how steam pressure might be turned into motive force by the cylinder-piston mechanism. Furthermore, more books about the steam engine were translated by the Translation Bureau (*Fanyi guan* 翻譯館), which was established in 1868 within the Jiangnan Arsenal for translating books about Western science and technology (Reardon-Anderso, 1991, pp. 29–52; Wright, 2000, pp. 24–127). By the end of the nineteenth century, five translations of marine engineers' manuals or textbooks had been produced. All of these publications were reprinted and circulated among Chinese literati, but none of the publications were included in any coherent technical course that educated engineers. Moreover, readers who did not have basic schooling in modern science and mathematics would find it difficult to gain the competence in the calculation of heat, pressure, and mechanical force, even if formulae were printed in the books. Isolated translations could not produce competent engineers any more than the school of naval construction at the Fuzhou Navy Yard.

A radical educational reform took place in 1904. The Qing government abolished the imperial examinations and started to formulate a modern system of education after the Western model. Public and private technical schools were established to provide technicians and engineers for the growing industries. Universities were also formed to house engineering departments and foreign professors

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were recruited. Private publishers which saw the commercial prospects of the reform started to produce translations of textbooks in the fields of modern science and technology at a much larger scale. These educational institutions would provide a greater number of engineers and technicians to China's industrialization.

To conclude, the introduction of steam power between 1838 and 1911 effected a great transformation of technology in China. Although the Chinese people initially misunderstood the steam mechanism, they experimented on it and successfully built a full-scale steamer. After trial and error, the Qing government realized that the existing technical expertise and tools were not enough to build more than one steamer and one engine. Hence, it established modern arsenals and navy yards that employed foreign technicians and imported machine tools. They made good technical progress by the end of the dynasty. They also trained Chinese workmen and a small number of engineers. However, financial difficulties hampered development until they were allowed to enter the market for profits. Although the Qing government intended to introduce the theoretical knowledge about the steam engine to the Chinese literati, that impact was limited.

From the early twentieth century, China underwent an industrialization in which the steam engine was the dominant source of motive power, although different types of motive force, such as the internal combustion engine and the electrical motor, were simultaneously introduced. According to an industrial survey conducted in 1937, 86 % of motive force in terms of horsepower in China's factories was steam powered (Liu Dajun, 1994, p. 96, 128, 160). More than 50 % of electricity was generated by coal-fired steam turbines (Tao Liumen, 1930, p. 490); locomotives were all steam driven (Yang Yi, 1948, pp. 1–4); and the vast majority of domestically built inner-river or ocean-going ships were still steam propelled (Wang Shiquan, 1948 pp. 2–3).

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